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Amsterdam

LATE GLACIAL PINGO AND VALLEY DEVELOPMENT IN THE BOORNE REGION NEAR WIJNJETERP, PROVINCE OF FRIESLAND, NETHERLANDS

PHYSICAL-GEOGRAPHICAL PART

By P. L. Ploeger

INTRODUCTION

This article is the result of practical fieldwork done by the author during the summers 1957—1959, under the guidance of Prof. Dr J. P. Bakker, of the Amsterdam University.

During this fieldwork, a pingo remnant was discovered, completely filled up with peat. A peat profile of 5,50 meter was bored with a Dachnowsky auger. A palynological investigation of this profile was carried out by Mrs. W. Groenman-van Waateringe. For the result, see the second part of this article.

The area investigated lies in the east of the province of Friesland, three kms. northwest of the village of Wijnjeterp (fig. 1). Borings were made every hundred meters, along parallel lines running north-south, one hundred meters apart. Borings closer together were also made when thought necessary. The borings were made with an auger. In favourable circumstances, borings up to 3,20 meters deep were possible. In general, it was attempted to reach the boulder clay layer.

The height of all the borings was measured with a levelling apparatus, using three known points in the area as standard. Peat samples were taken, using Dachnowsky's probe. With it sand samples from under the peat were also taken at several points.

The grain-size analysis of the samples taken was performed by the analists of the Physical Geographical Laboratory of the University of

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Amsterdam, under the direction of Dr H. J. Müller. For their help we here wish to express our thanks.

The investigation of heavy minerals was undertaken by Dr M. Bik, physical geographer, to whom we also owe our thanks.

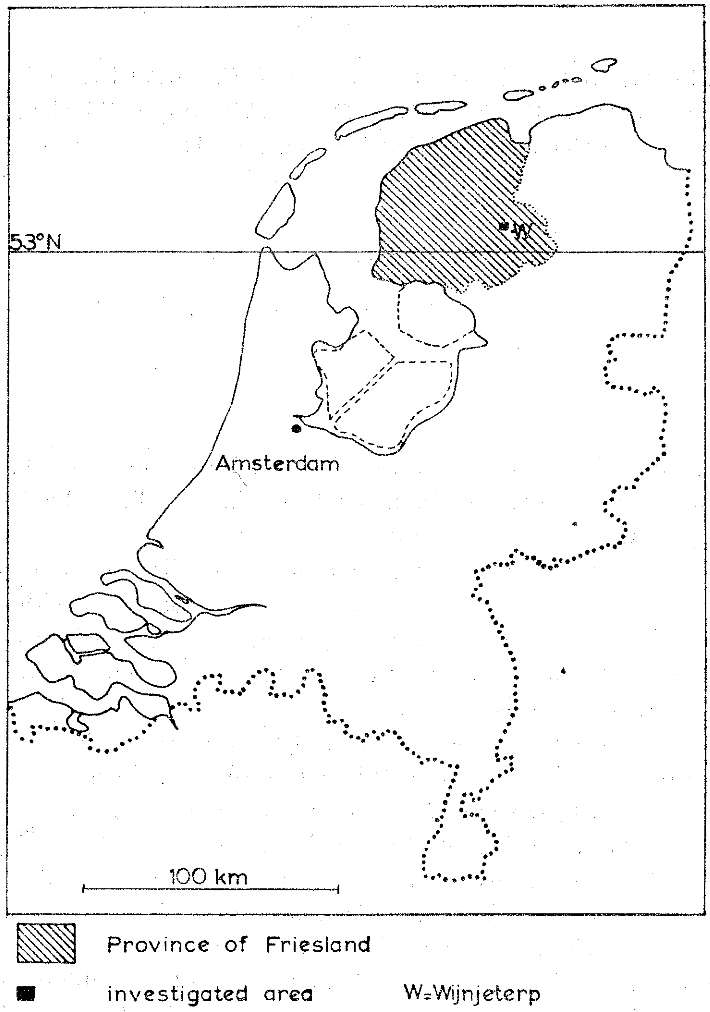


Fig. 1. Map of investigated area

The preparations for palynological examination were also done by the Physical Geographical Laboratory. For this we also had the full cooperation of Dr Müller and his assistants.

The authors wish to express their thanks to Mrs. J. S. Wensink-Clarke for the English translation.

SEDIMENTATIONS

In the investigated area, the following sedimentations were mainly distinguishable: (1) boulder clay; (2) cover sand; (3) peat.

The boulder clay

The boulder clay may be considered to date from the Saale Ice Age. From the map of the boulder clay distribution (fig. 2) the following observations can be made:

In the boulder clay area, it is possible to distinguish a main valley stretching from direction north-east to south-west.

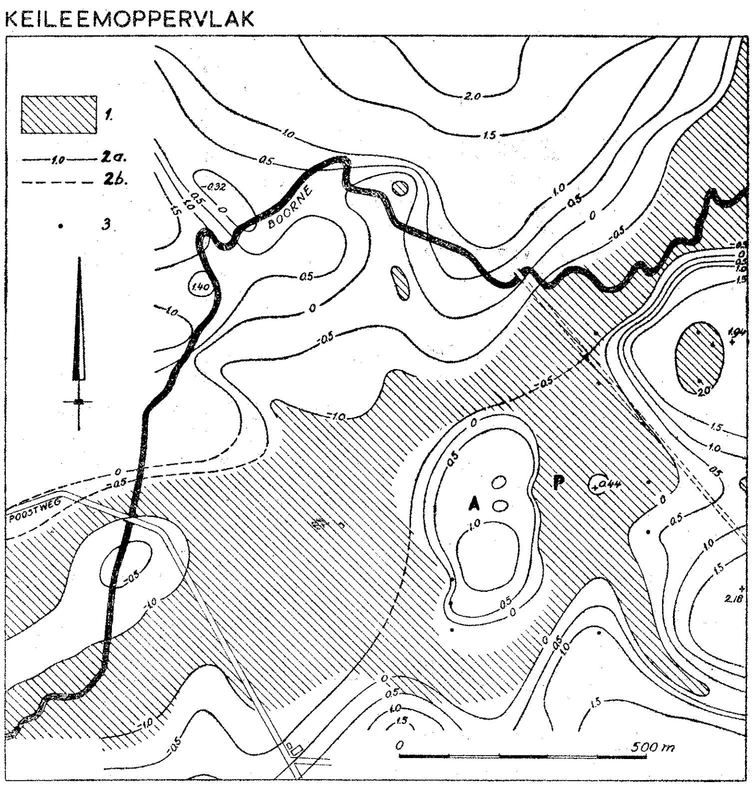


Fig. 2. Map showing depth of the surface of the boulder clay

1. area where boulder clay was inaccessible; 2a. depth of the surface of the boulder clay in metres + or — A.O.D.; 2b. supposed depth of the surface of the boulder clay in metres + or — A.O.D.; 3. borings in which solifluction deposits were observed

In the greatest part of the valley, the boulder clay was inaccessible. Therefore it was impossible to determine if this is an erosion gully in the boulder clay.

There are several examples of valley narrowing to be seen and if there has been erosion of any importance, this was at the most enough to form an erosion gully with a maximum width of that of the present gully at its narrowest point.

One can expect important erosion to have been caused by streaming of sub-glacial melt water, when the ice was more or less stagnant, and also, although to a lesser degree, from ice blocks. During the Eemian Period, the amount of water and the fall-gradient were too small to cause wide

SEDIMENTATIEKAART

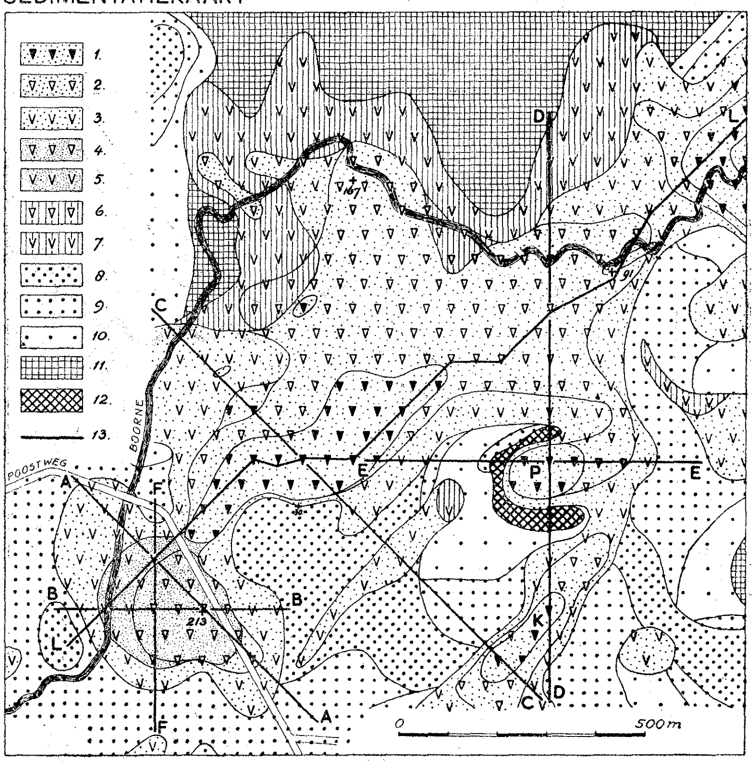


Fig. 3. Sedimentation map

1. peat, thickness more than 1,0 m, grown on cover sand; 2. peat, thickness 0,50—1,0 m, grown on cover sand; 3. peat, thickness less than 0,50 m, grown on cover sand; 4. peat, thickness 0,50—1,0 m, grown on loess; 5. peat, thickness less than 0,50 m, grown on loess; 6. peat, thickness 0,50—1,0 m, grown on boulder clay; 7. peat, thickness less than 0,50 m, grown on boulder clay; 8. cover sand, thickness 2,0—3,0 m, sometimes more than 3,0 m; 9. cover sand, thickness 1,0—2,0 m; 10. cover sand, thickness less than 1,0 m; 11. boulder clay cropping out; 12. rampart of the pingo remnant; 13. location of the cross sections: A—F and L (fig. 6)

or deep gullies in the boulder clay. There are indications that the gullies are related to the manner in which the boulder clay was deposited, since it is noticeable that most gullies in the north of our country are of the same width, and run in one direction, namely approximately northeast-southwest, which direction co-incides with that of the movement of the Saale ice sheet, for a long period. The boulder clay can have been deposited by the ice in the form of approximately parallel gullies, separated by boulder clay plateaux.

The boulder clay surface shows further depressions in addition to the main valley. Only one of these, namely a gully approximately 250 metres long, in the S. E. can be, in my opinion, an erosion valley, as indicated by the shape. The remaining depressions indicate a disordered sedimentation of boulder clay. This disorder was probably greater, but is now less visible, as locally the weathered boulder clay especially, has disappeared by solif uction. We can consider the more or less thick pebble sand deposits in the borings shown in fig. 2 to be solifluction deposits.

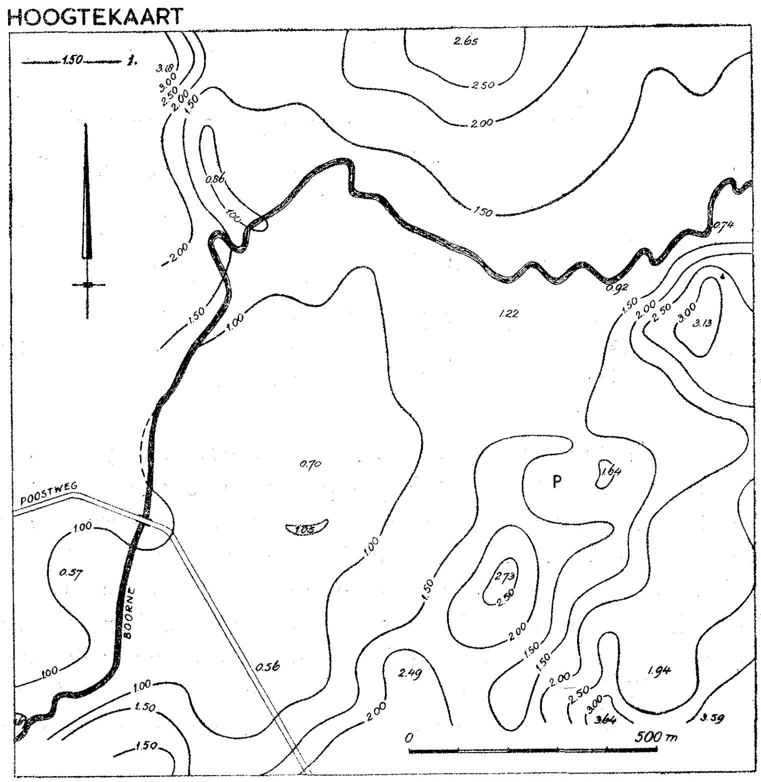


Fig. 4. Contour map

1. contour-lines in metres above A.O.D.

The boulder clay is less undulating in the northern part of the area, where it comes to the surface. It is possible that here the boulder clay was evenly deposited. Possibly the south exposure caused more levelling solifluction. In this region no filled-up depressions could be established. The possibility still remains that the solifluction material was shifted into the valley. However this was impossible to determine. Further it must be considered that this surface has been worked by man for centuries.

The boulder clay blocks in the rampart of the pingo remnant, displaced by solifluction, are not shown in fig. 2.

From grain size analysis of a few of the boulder clay samples (see fig. 7 and 8), it is noticeable that one of the maxima occurs in the fraction where the cover sand also shows a maximum, and that a second maximum occurs in the loess fraction.

From several of the boulder clay samples the fractions from 0,6 to 1 mm were examined for roundness. The method of André Cailleux was used. The results are given in the following table (Table I).

Angularity

Table I

Boring	Depth	Angular	Smooth shining	Clean round-dull	Total counted
90	230—250	35%	28%	37%	134
161	120—125	44%	23%	33%	162
163	173—177	17%	13%	70%	300
171	120—125	27%	35%	38%	159
180—2	300—320	47%	33%	20%	100
216	40—65	52%	21%	27%	66

André Cailleux distinguishes a fourth group, namely that of dirty round-dull sand grains. From this group there was not one example.

From the above table it may be observed that a large percentage of the eolian affected grains are absorbed in the ground moraine. This is to be expected, since during the expansion of the ice in the proglacial zone, periglacial circumstances may be assumed. In a periglacial area wind action is of great importance. In front of the ice sheet eolian sand will have been deposited here and there, perhaps over large areas. This sand will then have been covered by the inland ice and pressed into the ground moraine as a result.

It is known that in the north of Holland directly under the Saale ground moraine the so called pre-moraine complex is composed of drift sand, The smooth shining grains give evidence of long transport by rivers. Therefore in the ground moraine fluviatile or fluvioglacial sands must have been absorbed. (In the discussion of the heavy mineral analysis we return to this point).

The angular grains can have originated from break down of quartz--containing stones in the ground moraine. A second possibility is that they originated from fluviatile or fluvio-glacial deposits, but then from sediments that had not been transported long distances by water before they were deposited.

The investigation of heavy minerals gave the following results:

Mineralogical composition of a few boulder clay samples

Table II

Boring	Opaque	Tourmaline	Zircon	Garnet	Rutile	Titanite	Staurolite	Disthene	Andalusite	Epidote	Hornblende	Augite	Hypersthene	Saussurite	Topaz	Depth
161	19	2	26	22	10	—	2	—	3	20	13	1	—	—	—	120—125
163	17	5	33	17	8	2	3	—	1	22	5	1	2	—	1	173—177
171	24	2	19	9	8	—	2	1	3	34	17	1	—	—	—	120—125
180b	41	3	10	21	13	—	2	1	2	25	19	1	—	—	—	300—320
216	25	3	15	10	11	—	—	—	—	38	20	1	—	—	—	40—65

These samples contain such percentages of garnet, epidote and hornblende as can only classify the sediment as belonging to the A-province. Notable are the high percentages of zircon and rutile.

This can be due to the granular composition, so that these variations are of a granular sort. If there is a high percentage of the finer grain fraction, zircon and rutile may be present because these minerals are generally of small particle size.

Hornblende, on the other hand, increases above the 0,150 mm.

A second possibility is that this may be a mixture of the A-association and the Enschede-association. The first is from the north, the second from the east in origin. But this still leaves the high percentage of rutile unexplained.

The reasonably high percentage of clean round dull grains, and the grain size analysis indicate strong absorption of eolian sand by the ground moraine.

Mineralogical analysis indicates a northern origin, with possible absorption of eastern matter, that may have been carried by the rivers from the east. The latter is also indicated by the comparatively high proportion of smooth round grains. This also infers that the eastern material must have been transported over large distances, before being absorbed in the ground moraine.

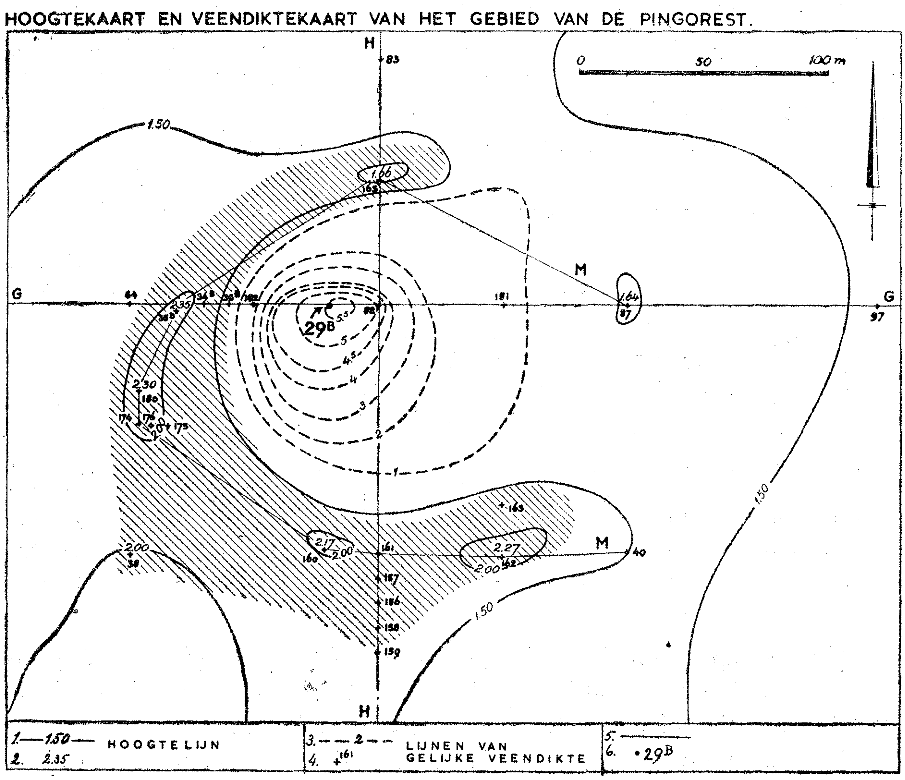


Fig. 5. Map showing countour-lines and thickness of peat in the area of the pingo remnant

1. contour lines in metres above A.O.D.; 2. maximum height of hillocks in rampart of pingo remnant; 3. lines of equal peat thickness in metres; 4. site and number of borings; 5. location of sections G, H and M (fig. 6); 6. location of the pollen diagram profile of Mrs. W. Groenman-v. Waateringe

On the above grounds, we postulate that the sand represented by the smooth, shiny grains must have originated from the northwest German fluvial pre-Saale deposits.

Cover sand

With exception of the northern region sand is deposited on the boulder clay in the whole area. This is mainly eolian sand, as is to be seen from:

1) the granular composition

2) partly from the morphology of the landscape and the altitude.

The fairly high to high percentage of clean dull round grains is no evidence of eolian sand deposits.

The sand under the wide peat area is considered to be cover sand by virtue of its position with relation to the north and south bordering cover sand areas. It is possible that there, after sedimentation of the sand, drifting of some finer fractions took place, due to slow-streaming water. It is also true for the cover sand lying higher up, that water washing and/or solifluction occurred as a result of which coarser or finer sand, or layers of sand and fine gravel are encountered in places.

In general, it can be said that the effect of the deposits of cover sand works on the one hand to lessen the relief, and on the other hand to increase it. This is to be seen by comparison of figures 2, 3 and 4.

In figure 2, two gullies are apparent to the north and south respectively of the isolated boulder clay. Also approximately in the middle lies an isolated boulder clay block, separated from the remaining boulder clay by two wide depressions. These gullies are all completely or partly filled up. The gully in the south-east has completely disappeared.

In the northern part of the region, there is little, or no cover sand deposited, so that lower parts of the boulder clay are still visible on the relief map, and also on the sedimentation map, from dispersion of the peat.

By virtue of the distribution and thickness of the cover sand (see fig. 3) we have come to the conclusion that it was deposited by south-west winds. This is indicated by the following facts:

1) Two gullies or depressions in the boulder clay surface, running SE—NW are completely, or almost completely filled with cover sand.

2) In the southern cover sand area are two shallow gullies, lying SW—NE. Here, it must be noted that the eastern gully does not completely coincide with the original boulder clay depression as regards position and size. Both gullies have been caused by deflation.

The two facts as above can be explained by both a NE and a SW wind. The presence of relatively thick cover sand on the north slope of the boulder clay surface in the south, and the complete or almost complete, absence of cover sand on the south slope of the boulder clay in the north indicate that there must have been a southern component in the wind, that deposited or removed sand. Therefore only a south-west wind remains possible.

The thick cover sand deposit in the utmost north-east of the region seemingly contradicts the above reasoning, but this can have been deposited on the leeside of higher, more westerly situated boulder clay.

Slightly south-west of the middle of the region, lies an outstretched peat area, with peat thickness of more than 1 metre. Seven borings in this area showed a thickness of peat of 120, 140, 150, 155, 155, 190, 193 cm respectively. This peat was formed on sand.

This reasonably deep hole was formed because here less cover sand was deposited, while on the east and west side the original valley was completely filled up.

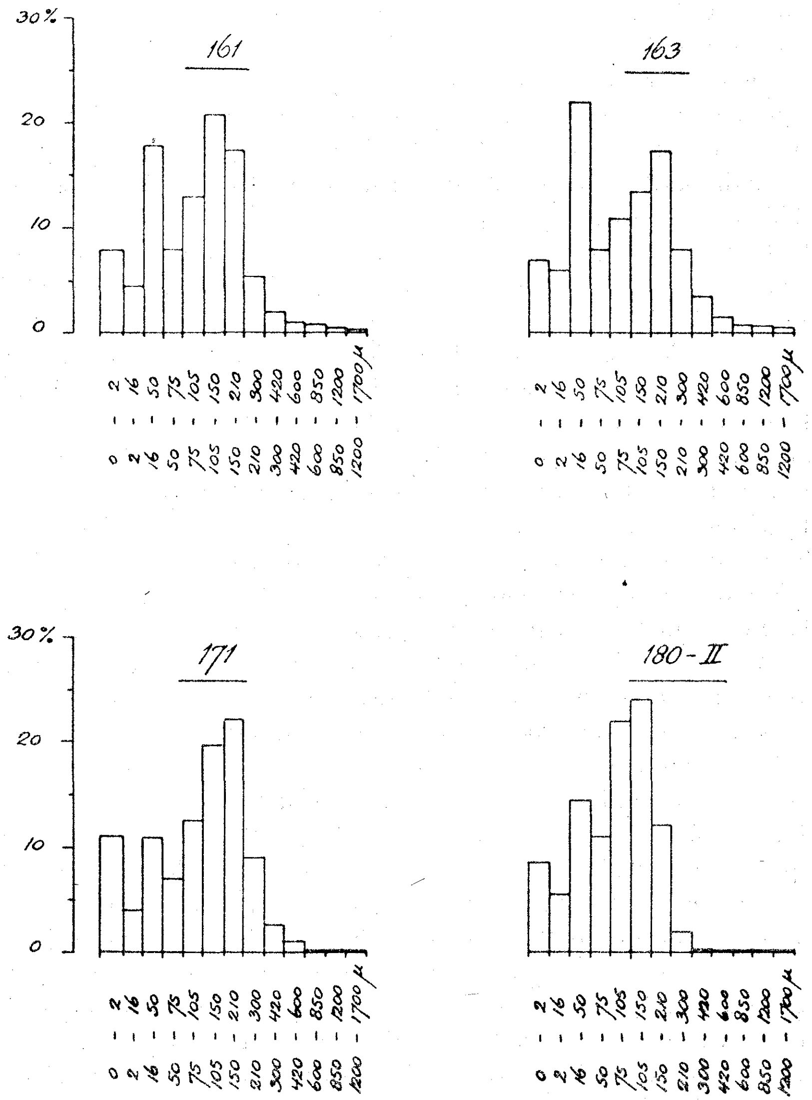
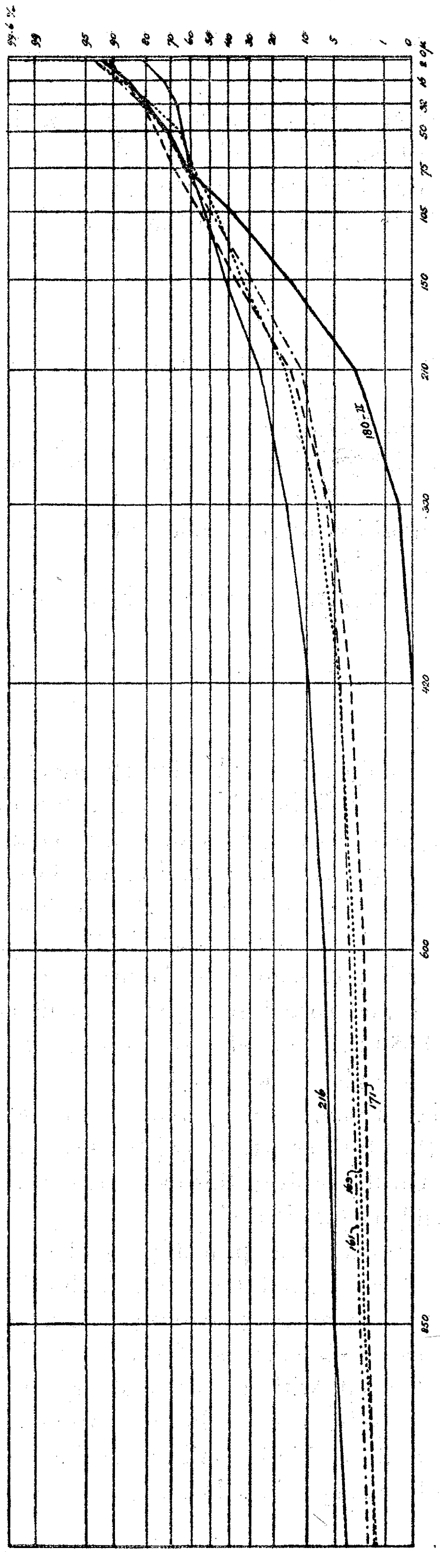


Fig. 7



99.6 %
99
95
90
80
70
60
50
40
30
20
10
5
1
0
0 μ
16
32
50
75
105
150
210
300
420
600
850
180-II
216

Fig. 8

Boring 91 (fig. 3) gave indications of an earlier, deeper gully in the present cover sand surface. Below this, at a depth of 215—240 cm dark greyish-brown loam, rich in humus, was found. Below this was yet more fine sand, and at a depth of 260 cm angular gravel was found, composed entirely of flints.

Other sediments surrounded or contained by cover sand

Layers of sand containing loam, and peat layers, or peat residues were encountered in eight borings. They are situated together in one area to the south.

The granular composition of such a loam-containing sand layer from boring 30 (fig. 3) is given in fig. 9.

Notable is the large percentage of the loess fraction 0.016—0.05 mm.

Loess

In the south-west of the area under investigation, a bowl-shaped depression is encountered. This is filled from bottom to top respectively with a thin layer of pebble sand, a sedimentary complex consisting of alternating thin layers of peat and fine sand, a thin loess layer, and finally a peat layer that links up with the peat surface in the remainder of the Boorne valley. (See fig. 3 and the profiles A, B, F and L).

The result of the grain size analysis of the loess is given in fig. 9 and 10 (boring 213). It is a well sorted sediment, containing 59,5% of grain size fraction 0,016—0,050 mm and 34% of the fraction 0,050—0,075 mm. The humus content is high, namely 17,1%.

Samples were taken from above, in and below the loess for palynological examination. (See further article by Mrs. Groenman-van Waateringe, boring 213). On the basis of this examination, the loess was found to date from the Old Dryas Period.

The sedimentation process was probably as follows:

During the Old Dryas Period there was a bowl-shaped depression in the cover sand, where there was possibility of peat formation. Perhaps there was a tundra pool. Thin layers of fine sand were now and again blown over the peat formed, with a thickness varying from three to five millimetres. The peat layers vary in thickness from two to seven millimetres. The sand from these thin layers becomes increasingly fine towards the top, and gradually changes into loess.

At the edge of the depression the loess layer becomes thinner and lies on the cover sand.

During, and after the loess sedimentation no more sand was deposited by the wind. The loess, and the peat above it contain no sand.

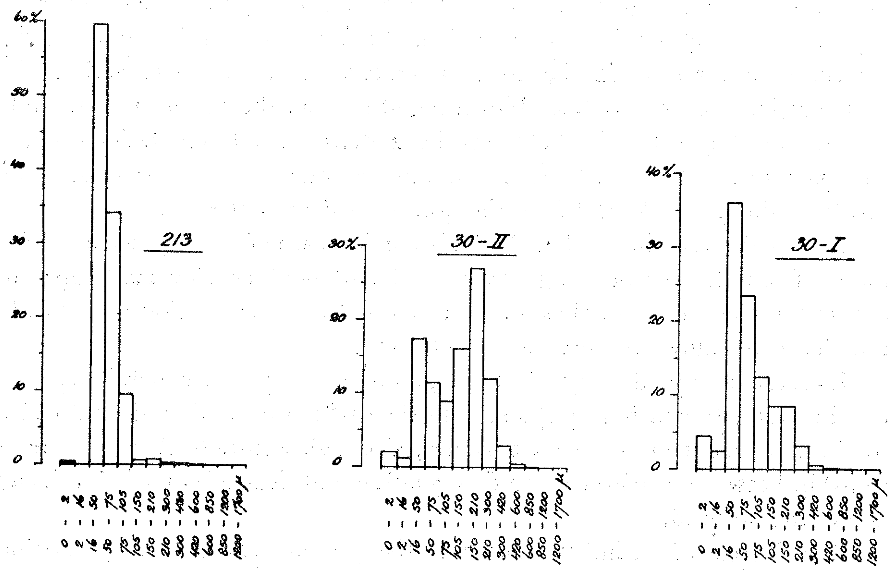


Fig. 9

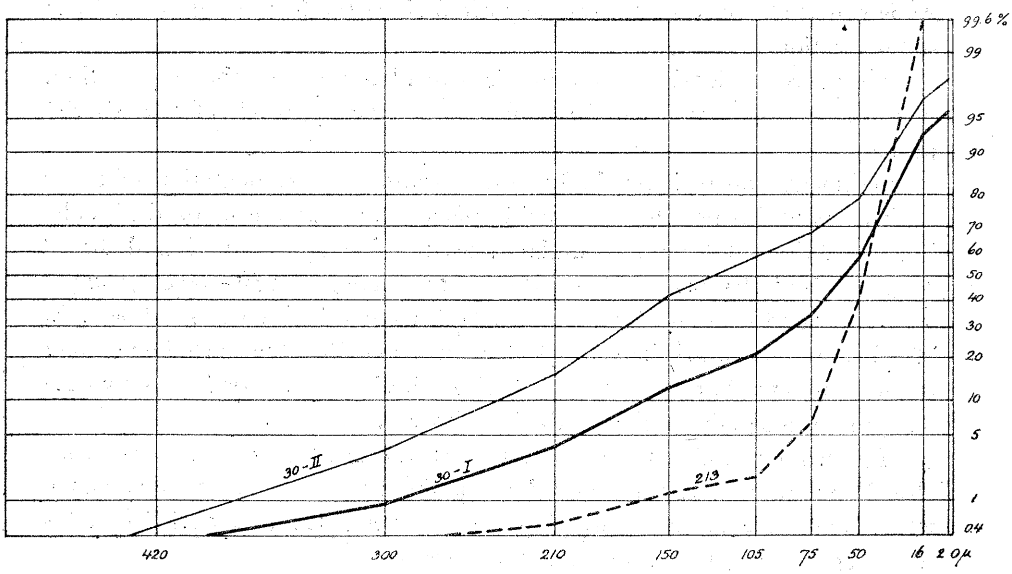


Fig. 10

This corresponds with the results of the investigation of the peat from the pingo remnant, where above a depth of 4,15 m, there is also no inorganic matter to be found in the peat.

Method of sedimentation of the loess: The loess can have been transported by air from great distances, but if this is so, then loess must be deposited throughout the whole region. In fact, no loess is found on the surface of cover sand in the area. Therefore, as a secondary action, the loess particles must have been blown together from the surface to a suitable spot where they could be held fast by a dense marsh vegetation — here we again draw attention to the high humus content of the loess and the result of the palynological investigation — and by water.

A second possibility is that the loess particles are of entirely local origin, blown from the surrounding cover sand and boulder clay landscape, to collect together at a suitable spot, at a time when the vegetation was already too dense to allow for drifting of the sand.

Increase in the density of the vegetation and not a general decrease of wind velocity will have put a stop to the drifting of sand, and finally also to the movement of the loess particles, although naturally there is a relationship between a denser ground vegetation and decrease of wind velocity along the ground.

If a decrease in wind velocity was the primary cause of the cessation of cover sand sedimentation, then during storms, which must have occurred sometimes, there must have been some sand transported and deposited. As is stated above, no sand was deposited since the beginning of the loess sedimentation.

Therefore a denser vegetation is considered to be the explanation. This denser vegetation can be explained by the approach of the Alleröd period.

Sedimentation of loess, before the cessation of sedimentation of cover sand is then also possible in suitable places, for example in tundra pools. This is indicated by the granular analysis of samples 30—1 and 30—2 (fig. 9, 17 and 19). Sample 30—1 is taken from a depth of 50—60 cm, sample 30—2 from 54—66 cm, 10 cm apart, both from a thick cover sand deposit. 30—1 shows a clear maximum in the loess fraction, 30—2 seems to be a second phase sediment, but here there is definite indication of mixing of two sediments as a result of the method of boring.

The loam containing sand layers, with layers of peat or peat residues already mentioned can perhaps be explained as traces of tundra pools, which were able to collect drifting loess particles during a period of relatively sparse vegetation on the cover sand.

PINGO REMNANT

At the point P on the sedimentation map (fig. 3) a deep bowl in the cover sand and boulder clay surface was encountered. This bowl is entirely filled with peat. The peat in the uppermost layer corresponds with that of the peat in the Boorne valley and in the peat filled gully K (fig. 3). As a result of this, the pingo remnant was completely hidden from the naked eye. By chance, one of the borings from the network fell almost in the middle of the bowl, and the discovery of extra peat thickness gave cause for further investigation.

On the south, west and north sides a ring of several small hillocks was found. These are further referred to as the „rampart". The rampart is at its maximum 1,05 m higher than the surface of the peat in the bowl. On the east, and partially on the north side, the flat peat surface is not interrupted by hillocks.

Twenty one borings were made in, and between the low hillocks and twenty four in the peat in the bowl.

The peat thicknesses measured can be seen in fig. 5 and in the profiles G and H (fig. 6G and 6H).

The maximum thickness of the peat was 5,50 m. Here samples of the whole peat profile were taken for palynological examination. (See appendix by Mrs. Groenman-van Waateringe).

As can be seen from fig. 2, 3, and 4, the rampart lies on the outer north--eastern edge of the isolated boulder clay area, that is covered by a more or less thick cover sand layer. The rampart forms a slight elevation on this north-eastern edge of the boulder clay, and is therefore hardly noticeable in the terrain.

The borings in the highest parts of the rampart gave the following impression of its composition and formation (see appendix). (In fig. 5 the borings taken for the profiles given in fig. 11 to 15 are given).

1) The ground gives the impression of having been worked.

2) The profile shows in general an alternation of layers of cover sand, cover sand with lumps of loam, pebble sand and boulder clay.

3) In places one or more thin boulder clay layers alternating with cover sand are encountered, while immediately following (at an interval of 1 metre) the boulder clay is absent. These isolated blocks of boulder clay are further referred to as boulder clay blocks.

4) The boulder clay from the boulder clay blocks that are found above the boulder clay in situ is obviously oxidised, and brittle in structure.

Our interpretation is that the rampart consists mainly of solifluction material that orginated in a pingo that existed at the point where the bowl now is.

For this view, we have the following arguments:
1) the structure of the rampart, already discussed
2) the morphology of the terrain
3) the position of the rampart around the deep, peat filled bowl.

This pingo was situated at the intersection of two gullies in the boulder clay surface, and at the eastern edge of the isolated boulder clay area.

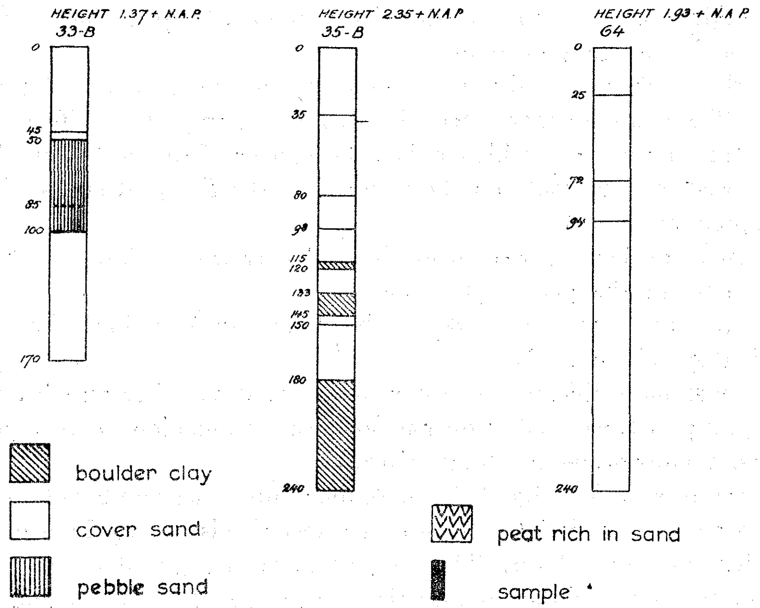


Fig. 11

The histogram and summation curves 161 and 163 (fig. 7 and 8) give an idea of the granular composition of two sandy boulder clay blocks that were met with in the pingo rampart at 34—69 cm above Ordnance Datum and 9—13 cm below Ordnance Datum respectively.

They are badly sorted.

180-II (fig. 7 and 8) is boulder clay taken from 90—160 cm under Ordnance Datum and is the last sample that can be bored from a boulder clay layer that lies from 53 cm above to 1,11 m below Ordnance Datum. On grounds of position, consistency, and colour, we consider this to be the undisturbed boulder clay in situ. Above this boulder clay, two boulder clay blocks from 25 and 35 cm thickness are found. A sample of the sand between the two layers was taken (see 180-I, fig. 16 and 17). The sand contains an admixture of fine and coarse material and corresponds with badly sorted cover sand.

160, 174, 175-II show the granular composition of the sand that is present under the boulder clay blocks. They are well sorted fairly coarse cover sands. 175-II has a relatively large proportion of coarse material (fig. 16 and 17).

175-I shows the granular composition of sand above a boulder clay block. This sand is better sorted than 175-II (see fig. 16 and 17).

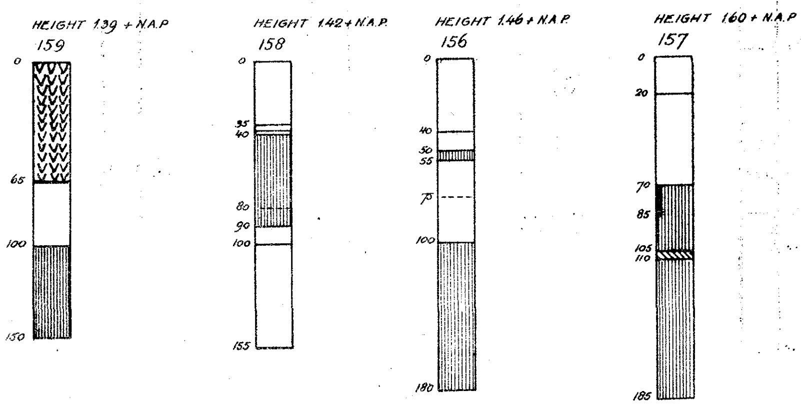


Fig. 12

These sand samples were taken from sand layers that gave the appearance of being undisturbed.

From above, it would seem that the material coming from the pingo by solifluction, was afterwards covered by cover sand. We return to this point later.

The great differences in sedimentation over short distances are shown by fig. 11—15.

On the eastern side of the deep, peat filled bowl the rampart does not protrude above the peat (see fig. 3 and 5).

This does not imply that no solifluction took place in this direction. This was not determined. It is possible that the elevated material in the edge of the original pingo, here sunk after melting of the ice core. This gives some explanation for the asymmetrical form of the bowl.

A calculation was made to estimate approximately how much material was raised out of the bowl by the ice lens and displaced by solifluction.

For this purpose the deep bowl was considered to be a cone, with a circle radius 40 metres as base (the cross section of the bowl at Ordnance Datum is namely 80 metres) and a height of 4,5 metres.

By virtue of the information from borings, it is assumed that the boulder clay, and a cover sand layer 0.5 metre thick were raised. For the boulder

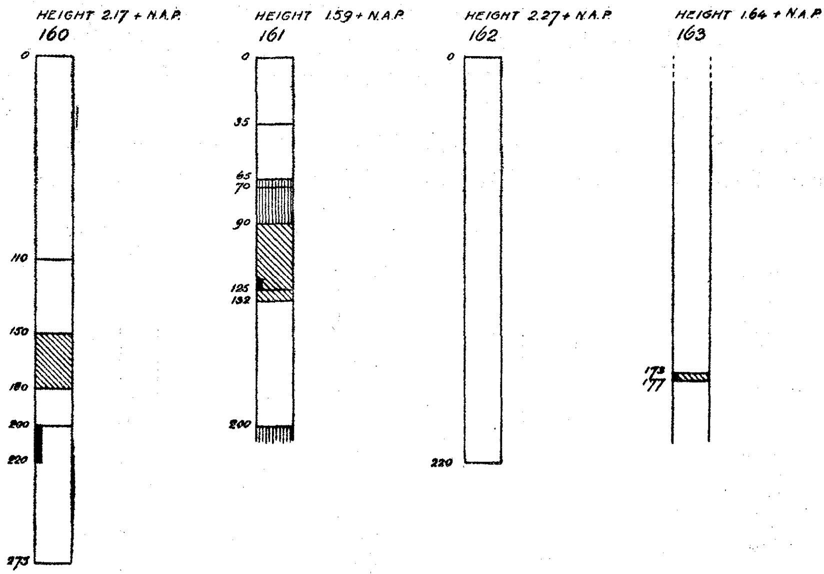

HEIGHT 2.17 + N.A.P.
160
HEIGHT 1.59 + N.A.P.
161
HEIGHT 2.27 + N.A.P.
162
HEIGHT 1.64 + N.A.P.
163

Fig. 13

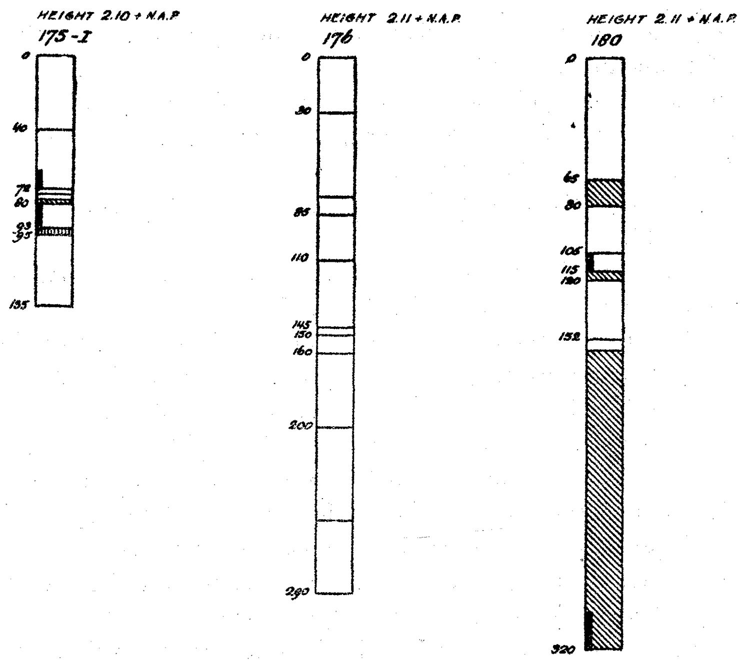

HEIGHT 2.10 + N.A.P.
175-I
HEIGHT 2.11 + N.A.P.
176
HEIGHT 2.11 + N.A.P.
180

Fig. 14

clay level, the depth of the boulder clay from boring 182 was assumed. This was 0,46 metre below Ordnance Datum. 0,50 metre was used, as a round figure.

The volume of the cone was calculated to be 7543 cubic metres.

If one assumes the total thickness of the solifluction material from the rampart to be one metre, then the area of the wall must be 7543 square metres. The width of the wall is then calculated to be 23 metres.

Measurements in the terrain do not completely agree with this figure. The wall seems to be wider at some places. On the southern side it is 35 metres. On the other hand, it is not a closed wall. Also some cover sand may have been deposited on the pingo, as a result of which more material was transported by solifluction than was calculated.

In the rampart, noticeably little pure boulder clay is found. In the S—N profile of the borings 159—161 much pebble sand is found.

In the five borings taken every 10 metres from the S—N line 10, 50, 110, 115 and 25 cm pebble sand respectively was found.

Pingos always have a steep slope, angles of inclination being from 20°—30° (Tricart, p. 134).

If we assume in this case that the angle of inclination was 30°, and the cross section of the pingo 80 metres, then the calculated height is here found to be 23 metres above Ordnance Datum. This calculation is also made to try to determine if solifluction over a distance of up to 60 or 80 metres from the present edge of the deep hole could have been possible. This seems to be the case.

DURATION OF THE PINGO

On pages 214 and 215 it was noted that it could be proved that at several points on the rampart layers of solifluction material enclosed layers of cover sand. This can be seen very plainly in the profile of the borings 34B, 35B, 174 and 180 (fig. 11 to 15).

This cover sand gives the impression of being pure, undisturbed cover sand. Granular analysis of several samples of this cover sand shows that they are well sorted cover sands (see histogram and cumulative frequency curves 34B, 174 and 180-I, fig. 17). Sample 180-I is taken from the cover sand that rests on the boulder clay layer. Probably this is the reason that mixing of finer and coarser material occurs. This enclosed cover sand must have been drifted over the solifluction material after solifluction from the pingo had taken place at a certain time, or during a certain period.

It would seem that solifluction did not take place evenly in all directions, Most solifluction material was found on the south and south-west side. Especially in the south, in the form of pebble sand.

Granular analysis of a sample of this pebble sand shows that 21,5% is coarser than 2 mm, and although the sand is fairly badly sorted, it shows a definite alignment with cover sand. Here solifluction of boulder clay, with the driven cover sand, may have taken place. The boulder clay in this area also shows a maximum in the same fraction as the cover sand, so that it is also possible that the pebble sand is composed mainly of boulder clay, transported by solifluction.

Between the solifluction material, that seems to be deposited in bands, there are points where no, or almost no solifluction material was deposited. Here more or less thick cover sand is found (see fig. 11—15, borings 160, 162, 64).

The top layers of the boring profiles shown in fig. 11—15 consist mainly of sand. This often gives the impression of having been worked. This can have been caused by ploughing of the top layers. (A farmer told us that one of the hillocks was used for the cultivation of rye during the last war.) On this hillock, where borings 34B and 35B were made, there were many mole hills. These were covered with fairly large flints, with maximum measurements up to 7 cm. The top sand layer here must also consist of solifluction material. At boring 38 pebble sand was found directly on the surface.

In conclusion, it can be said that:

1) Pure sand was found between the solifluction material, in thicknesses varying from 30 to 135 cm.

2) Between, on top of, or alongside this solifluction material cover sand thick from 1 to 2,40 metres is found.

3) Solifluction material is also found on the surface. After the disappearance of the pingo, there were no important deposits of cover sand.

4) Solifluction took place mainly on the south and south-west side of the pingo.

The duration of the Younger Dryas period is calculated to be about a thousand years using the C-14 method (*Geol. History of Ned.* p. 101). During this period there was comparatively little cover sand deposited in the north of our country. This indicates that there can be no question of a continuous sedimentation of cover sand.

The pingo existed during a period when sand of a thickness from 1 to 2,40 metres was deposited. For this much time was needed, so the pingo must have been of long duration. Comparing this with the duration of the Young Dryas period, we obtain a duration of a thousand, or several thousand years. Existing pingo can also be several thousand years old (Tricart, p. 134; Müller, 1959, p. 114).

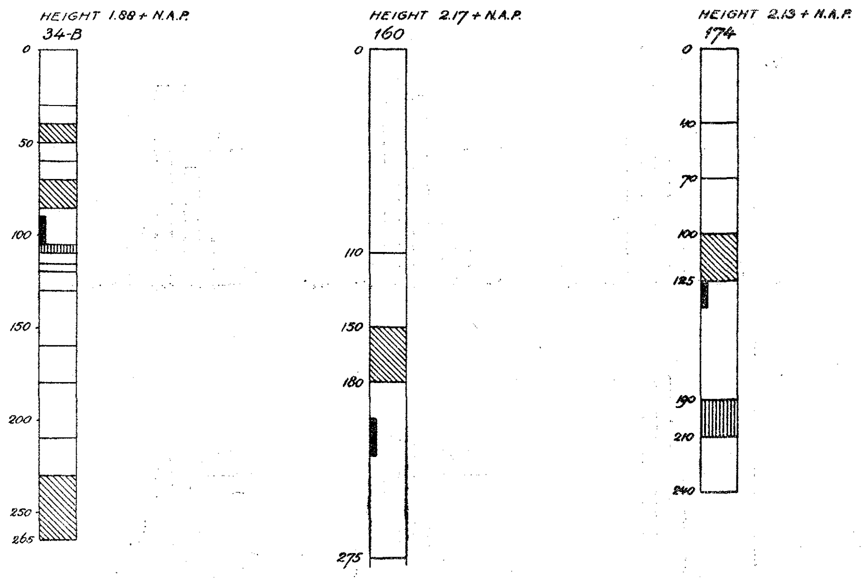


Fig. 15

AGE OF PINGO

Mrs. Groenman-van Waateringe has dated the oldest peat from the profile from the pingo remnant as being from the Old Dryas period (see p. 228). We assume that the growth of peat started soon after the disappearance of the pingo. If this is true the pingo existed until the Old Dryas period.

For the origin of the pingo no dateable evidence was found.

RELATIVELY RAPID GROWTH OF PEAT IN THE PINGO REMNANT

In the pingo remnant, the growth of peat was relatively rapid during the Old Dryas, a fact that one might not expect in a tundra climate. But between the present tundra at high latitudes and that then existing in the Netherlands there is a.o. the following difference, namely that the sun's position at 53 N was much higher than is now the case in the present day tundra. This must have led, among others, to the fact that the water in the lake in the remnant had a reasonably high temperature during the summer. This must have been favourable for life of several organisms. Above all, as a result of the higher temperature the permanently frozen bottom under the lake must have lain much deeper, or not existed, as also occurs in the present-day tundra. This must have given rise to a continuous source of water rich in nutrient matter, from the region.

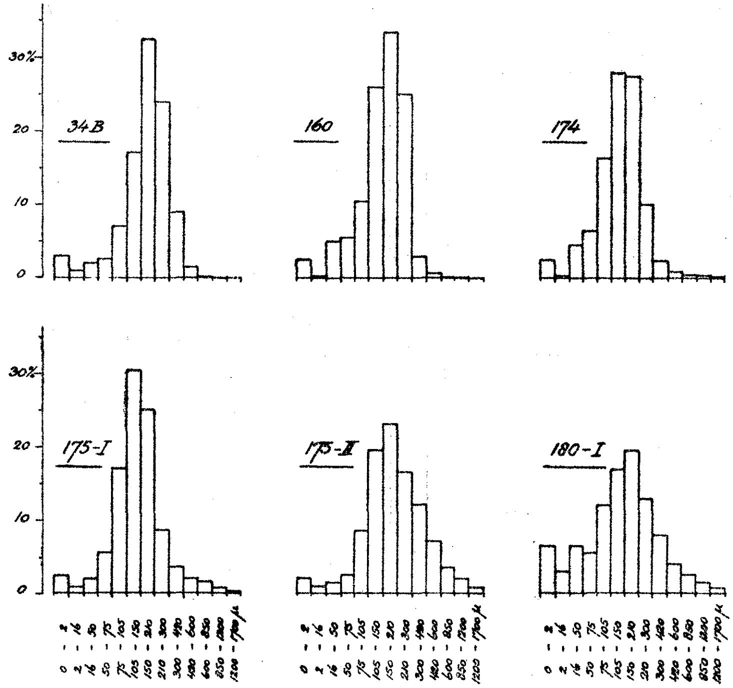


Fig. 16

We would also draw attention to the fact that the peat in the pingo remnant was formed in an eutrophic medium.

An X-ray analysis of boulder clay samples from the area gave the following results for the clay fraction smaller than 1/1000 mm. Montmorillonite 10%; illite 70%; kaolinite 10%; quartz 8 to 10%[1].

Finally, it must be noted that the peat here was more or less able to retain its original thickness due to the relatively low-lying position of the pingo remnant, so that it was able to continue receiving water from all directions, and settlement of the peat was prevented (see fig. 4, 5 and 6 E—H).

INVESTIGATION OF THE ROUNDNESS, ORIGIN, AND MINERALOGY OF THE EOLIAN SANDS

By virtue of the grain-size analysis, we consider the sands from samples 34B, 160, 174, 175-I, 175-II, 180-I, 249-I and also from samples 28B,

[1] The x-ray analyses were performed by Drs. T. Levelt at the Physical Geographical Laboratory in Amsterdam.

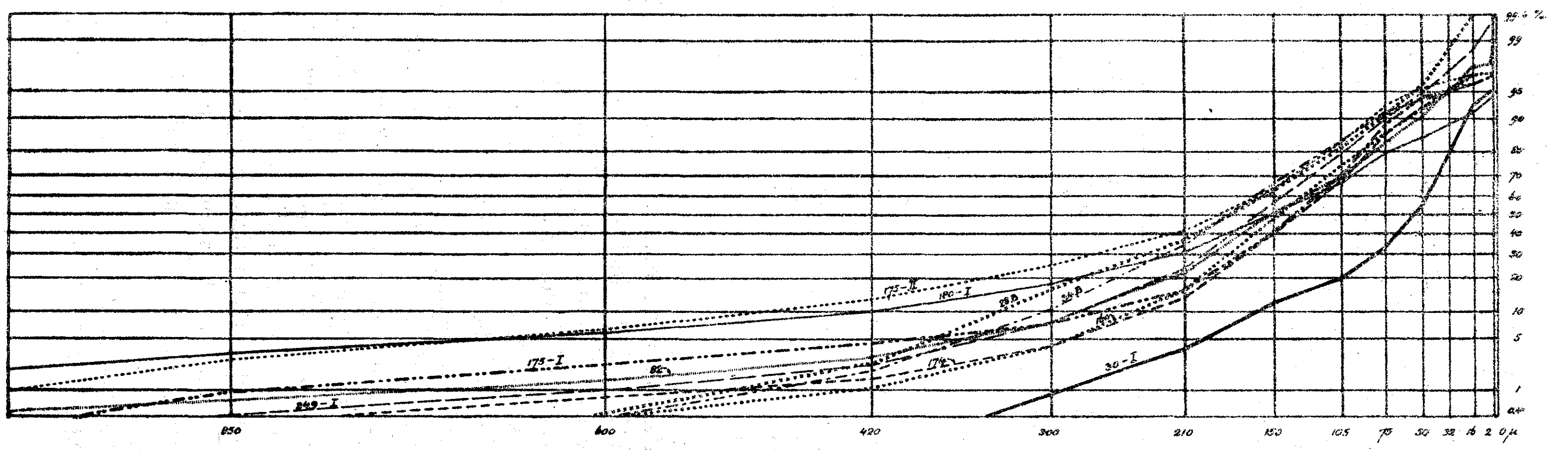


Fig. 17

29B, and 82 to be eolian sands. The latter three samples are taken from the sand under the peat in the pingo remnant (see fig. 16, 17, 18). The above samples were examined for roundness by André Cailleux's method.

The result is given in the table III.

Not one grain of the fourth category that Cailleux distinguishes, namely the dirty dull round grains was found.

Table III

Boring	Depth	Angular %	Shiny smooth %	Clean round-dull %	Total counted
34B	90—105	39	35	26	200
174	125—140	42	24	34	198
175—I	62—72	21	34	45	129
175—II	80—93	33	36	31	100
180—I	105—115	40	17	43	100
249—I	140—160	22	25	53	160
160	200—220	10	22	68	100
82	500—520	10	23	67	168
28B	540—555	4	17	79	200
29B	570—580	2	35	63	168

From the table, the following may be noted, namely:

1) The samples 34B to 249-I inclusive, all contain a large percentage of angular, and shiny round grains. Only in samples 175-I and 249-I is the percentage of clean round dull grains highest.

2) There is a marked difference in roundness between these samples, and those taken from under the peat in the pingo remnant (82, 28B and 29B) that contain almost no angular grains, but a much higher percentage of clean round dull grains. It must also be observed that during counting many grains were found that were well dull, but due to their shape, which was far from round, were assigned to the group of shiny smooth grains. These belong mainly to a transition state that one could call „smooth, more or less dull, but not yet round".

3) The sand from sample 160 noticeably agreed with that from under the peat in the pingo remnant (the same degree of roundness was found in no 163, which by virtue of borings and grain size analysis is assigned to the boulder clay).

Petrographic differences indicate differences in sedimentation.

The sands from 34B to 249-I inclusive (table III) can only have been transported short distances by wind, and therefore the angular and shiny smooth grains have not lost their original shape. The dull grains were already present as such in the material, from which they came by deflation. In this region a large amount of boulder clay is present at the surface. In the clay there is a fairly high percentage of dull round grains, and also a high percentage of angular grains. The above mentioned cover sands can therefore have originated from the boulder clay in the neighbourhood.

We do not think that they can have originated in the North Sea area, for then they will have been transported over great distances, and therefore be much smoother and duller. And above all, the mineralogical composition would then have to belong to the H-association, or a mixture of the A—H association, which is not the case (see Table IV). The mineralogical composition of the cover sand agrees with that of the boulder clay (see Table II on p. 205) and indicates a mixture of the A and Enschede-association.

Mineralogical composition of some cover sand samples

Table IV

Boring	Depth	Opaque	Tourmaline	Zircon	Garnet	Rutile	Titanite	Staurolite	Disthene	Andalusite	Sillemanite	Chloritoid	Epidote	Hornblende	Augite	Hypersthene	Sausserite	Topaz
175—I	62—72	20	4	19	3	8	1	6	4	1	1	—	30	17	2	—	—	—
174	125—140	32	4	23	5	2	—	3	2	4	—	—	42	11	2	—	—	—
34B	90—105	29	3	16	13	9	—	2	1	1	—	—	35	14	—	—	—	—
160	200—220	10	2	21	38	8	4	5	—	1	—	1	11	5	—	1	—	—
28B	540—555	20	5	8	30	5	—	5	1	2	—	—	26	11	—	—	—	—
175—II	80—93	16	5	11	4	8	—	2	2	4	—	—	38	24	1	—	—	—
A prov.		25	2	8	31	2	1	2	1	—	—	—	27	24	1	—	1	—
Enschede prov.		50	7	17	13	2	—	13	7	2	3	—	27	2	—	—	1	6

The eolian sand in the pingo remnant belongs to the eolian sand type that was precipitated proglacially during the Saale Glacial Period.

As regards roundness, sample 160 shows complete agreement with the premorenal eolian sand. It is found under a boulder clay layer 30 cm thick (see fig. 13). The possibility that the premorenal sand was also raised up in the pingo by the ice lens must not be overlooked.

According to us, further investigation of the roundness of the cover sand, from a complete cover sand profile will show there are definite differences. The degree of roundness will vary according to the climatic oscillation of the Vistulian. The degree of roundness will decrease when

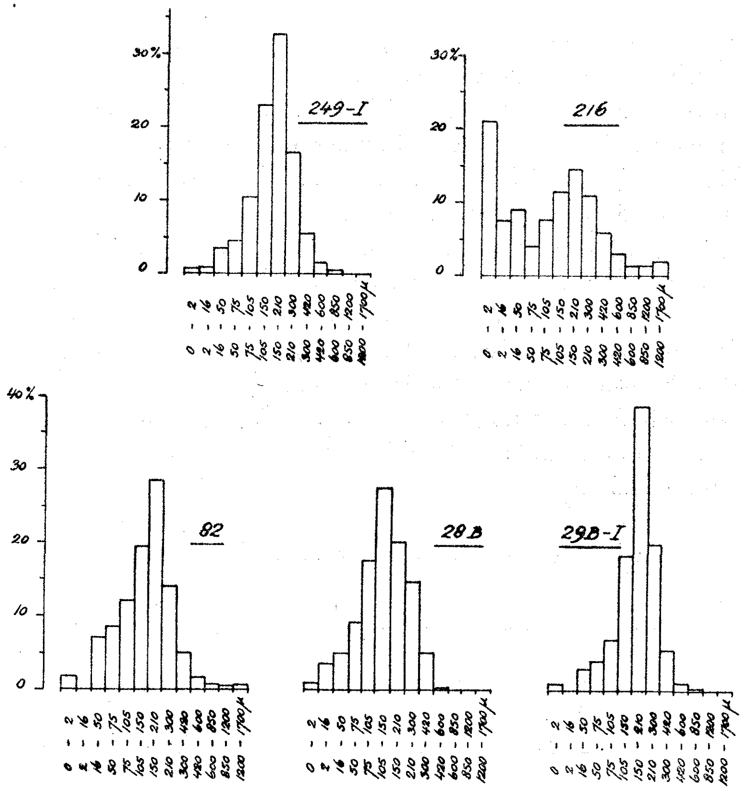


Fig. 18

the wind has less influence on the sand surface, due to better climate and denser vegetation. Cailleux (1942) showed a striking decrease in the percentage of rounded grains in Denmark, when the ice from the last Ice Age began to retreat. The same thing happened in N-Germany and N-Poland.

Possibly further investigation will also throw a new light on the so--called niveo-eolian sands. It seems namely impossible that niveo-eolian sands can show a large degree of roundness unless they are remodelled sands.

In conclusion, it may be said that further examination of the degree of roundness of eolian sands can bring new facts to light as regards their origin, the distances that they have been transported, and the ways by which this happened.

THE BOORNE

It is probable that the Boorne was forced to continually alter its course during the Late-Glacial Period, due to filling up of the wide boulder clay valley with cover sand. In the South-West, the valley is completely closed by cover sand. The closure must have been one of the reasons for the existence of marshy conditions in this valley after the disappearance of the permanently frozen subsoil and before the rise in sea level caused a general rise in ground water level. After the completion of sedimentation of cover sand, the Boorne ran through the lowest region of this cover sand. Possibly many ponds existed, and were slowly filled with peat. With the rising of the ground water level, the growth of peat also increased outwards. The Boorne must have kept a course for itself open through the peat. This course has been laterally displaced throughout the years, since now, with one exception, the Boorne does not run above the deepest part of the cover sand in any of the profiles. In the western part of the region, the Boorne is completely displaced from the most low-lying parts of the boulder clay, and now flows above the shallow-lying boulder clay. For a fairly large distance the Boorne now even flows through the boulder clay (see fig. 2 and 3), beyond the present peat covering. We can give no explanation for this. It was thought to be possible that the Boorne followed an old erosion gully, where previously a tributary had its course. But, in fact, this is impossible since the tributary would not have followed the fall gradient of the boulder clay surface consistantly. And, above all, this old erosion gully should then still be discernable, running in a NE direction beyond the present course of the Boorne. This is not the case.

The possibility of removal of the peat was also considered. According to information from the State Archives in Friesland, the Archive of the Opsterland Peat Company does not show that here peat exploitation took place.

Further, the possibility of a new course having been dug by man was considered. It then remains remarkable why exactly this part of the Boorne should have such a winding course. It is not likely that such a course would be dug by man. It is however, certain that the bed has been made artificially deeper.

Our request for information from the State Archives of Friesland received the following answer from Dr. J. Visser:

On S. v. Ockinga's map of Opsterland (1693) in B. Schotanus and Sterringa's Frisian Atlas, the Koningsdiep (Boorne) at this point has a trajectory approximately halfway between its present course, and the given ditch [2]. (Older maps are too much innaccurate). The reprint

[2] By „the given ditch" is meant the somewhat unordered arrangement of ditches, south of the big northern bend in the continuation of the present Boorne, east and west of this bend. The ditches suggest an earlier course of the Boorne along that route.

of this map in F. Halma's atlas (1718) also shows the same course, as does R. and J. Ottens's map of Friesland of 1739, J. H. Knoops's map (1762), A. van Krevelt's map (1781) (J. Kok, Vaderlandsch Woordenboek) and the map from C. van Baarsel and Son. The broad curve to the north does not appear until J. Witteveen's map in W. Eekhof's Atlas.

The reason for the alteration remains unknown.

The Boorne now flows in the western half of the region, through peat lying from 20 to 40 cm higher than the most low-lying peat, more to the south (fig. 4). This may be explained by the fact that the most low-lying peat is much thicker, and has therefore undergone more compression. This leads to drainage difficulties. These can possibly be remedied, by digging a main drainage canal through the lowest peat area, still keeping the water level in it high. Drainage of the peat filled gullies would then have to be along their axes. The present drainage system does not take the disorder of the terrain into account.

PALYNOLOGICAL PART

by W. Groenman-van Waateringe

INTRODUCTION

In connection with a soil investigation into the formation and origin of a pingo remnant in Wijnjeterp, a profile of 5,50 metre (No 29B) was bored, using a Dachnowsky auger. Samples for palynological investigation were taken every 10 cm, and prepared according to the acetolysis method of Faegri and Iversen in the Physical Geographical Laboratory of the University of Amsterdam.

The zonation was based on Firbas' system (1949). In the diagram *Corylus* is included in the tree pollen sum. A pollen diagram A, where the total percentage of tree pollen is represented as 100%, is drawn together with a diagram C, where the percentage of tree pollen is compared with the percentage of anemophile herbs, since the first diagram does not give a clear picture for the Late Glacial Period. The increase in the percentage of herbs in the Subboreal is also shown clearly in diagram C. Further, several samples from a peat layer above a loess deposit (No 213) were analysed, and also several samples from a boring on the edge of the peat area (No 167).

BORING NO 29B (fig. 5 and 19)

Stratigraphy

The oldest deposits in the pingo remnant at Wijnjeterp consist of a gyttjalike substance, in which much inorganic matter was found, and underneath probably pre-glacial sand. The edges of the pingo remnant, in which a pool of water must have formed during the summer on a *perenne tjäle,* must have been overgrown very quickly with *Cyperaceae* and *Gramineae,* as macroscopic traces of remains of these plants were found at a depth of 5,30 m in the profile of borings. This *Gramineae--Cyperaceae* peat continues until a depth of 3,95 m; from 3,95 to 3,75 m there is much *Equisetum,* and from 3,75 to 2,95 m we find *Hypnum* peat. From there until a depth of 2,55 m the peat is again formed of *Cyperaceae,* but from 2,55 to 2,45 m there is a single bright yellow band of *Gramineae* peat, and also from 2,12 to 1,95 m. After this *Hypnum* peat continues to 1,45 m, then wood peat. From 1,45 m until a depth of 1 metre, alder wood was found regularly in the auger, so that the boring had to be repeated several times. After this wood peat, *Cyperaceae* peat appears again.

Even now, the land inside the pingo rampart is notable for its moisture, and growth of *Cyperaceae* and *Caltha palustris.*

Zonation

The date of the deepest part of this peat profile may be placed in the Older Dryas Period of the Late Glacial. A definite Bølling oscillation cannot be found in this diagram. A high percentage of *Artemisia* occurs repeatedly, and indicates that the date of the beginning of peat growth is in the Firbas zone Ib (see also Van der Hammen 1953). Pollen grains from *Plantago, Rumex, Empetrum, Hippophaë* and also several pollen grains from *Helianthemum* and *Polygonum bistorta* were found. Pollen grains from *Centaurea cyanus* and *Sanguisorba* were not observed. The percentage of *Ericales* was still very small. The principal herbs were: *Cyperaceae, Gramineae, Compositae, Filipendula, Thalictrum* and *Galium.*

Between 4,10 and 4 m we observe a sharp fall in the percentage of herbs, while *Betula* shows a striking increase, followed by a slight increase of *Pinus.* This increase of arboreal pollen and decrease of non-arboreal pollen indicates the beginning of zone II, the Allerød Period, which continues until a depth of 2,80 metres. In fact during the whole period the percentage of *Pinus* remains less than that of *Betula* — the opposite of what occurs in other Dutch pollen diagrams from this period.

Zone III, the Late Dryas Period, is represented by an increase in the percentage of herbs, and, in the case of the diagram from Wijnjeterp, mainly by a decrease of *Pinus*. In this period the *Ericales*, namely *Empetrum*, shows rather high values, with a maximum at 9,1% (cf. Van der Hammen 1953; De Planque 1950; Van Zeist 1955; Casparie and Van Zeist 1960). *Myriophyllum*, *Potamogeton* and *Equisetum* show quite large values.

The final amelioration in climate (beginning of zone IV, the Preboreal) occurs at about 2 m beginning with a maximum for *Betula*. The percentage of non-arboreal pollen, without *Gramineae* and *Cyperaceae* becomes less than 10%. The *Ulmus* curve begins, followed by that of *Quercus*; real tundra plants such as *Artemisia*, *Hippophaë* and *Empetrum* no longer occur. The continuous *Corylus* curve begins comparatively late in this diagram, namely in the middle of zone V, the Boreal, and immediately shows a slight maximum. The transition between zones IV and V is placed at 1,70 to 1,60 metre, at the beginning of the *Corylus* curve after the intersection of the falling *Betula* curve and the rising *Pinus* curve. During the Boreal, *Pinus* is dominant, and *Corylus* only shows a slight maximum. *Quercus* begins to increase; *Tilia* and *Alnus* appear. At the end of the Boreal Period *Fraxinus* appears for the first time.

The intersection of the falling *Pinus* curve and the rising *Alnus* curve indicates the beginning of the Atlantic. *Quercus*, *Ulmus*, *Tilia* and *Fraxinus* show high values in the first half of the Atlantic. *Alnus* also occurs in high percentages (between 60 and 70%), probably caused by the local vegetation at the edge of the pingo remnant. The boundary between Atlantic and Subboreal is put at 0,75 m, at the decline of the *Ulmus* curve. In general this decline is attributed not to the climatic conditions, but to human influence (cf. Troels-Smith 1953, 1955, 1960; Van Zeist 1959; Iversen 1960). It must be noted that one pollen grain of *Plantago lanceolata* was found just above this boundary. The decline in the *Tilia* curve takes place much later, at the same time as the great increase of *Plantago lanceolata* (cf. Van Zeist 1959).

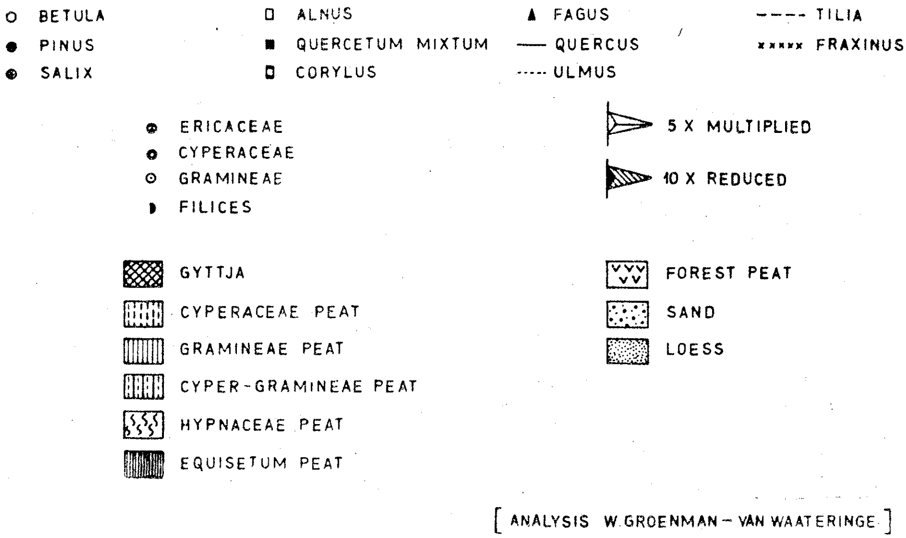
From a depth of 0,60 m under the surface we notice an increase in the percentage of herbs in which *Plantago lanceolata* shows rather high values. *Gramineae* bigger than 50 mu only occur in the top two samples; a few were identified as *Triticum dicoccum*. It would seem that in the top five samples we are concerned with a typical *Plantago-landnam* (Iversen 1941; Waterbolk 1954, 1956) although the local vegetation continues to play such an important part, that the percentages of the various herbs are hereby strongly influenced. The local vegetation at the time of the landnam consisted of *Cyperaceae* peat with *Gramineae*, containing therefore — among others — *Gramineae*, *Compositae* (e.q. *Eupatorium cannabinum*), *Menyanthes* and *Filipendula*. A proportion of the observed herb pollen is therefore to be attributed to the above and not to the landnam. For a landnam the presence of true meadow plants such as *Chenopodiaceae*, *Artemisia* and *Plantago lanceolata* is necessary. In the first place we notice an increase in the percentage of herbs, namely *Gramineae*, *Plantago lanceolata*, *Compositae*, *Rumex* and *Filices*, and at the same time a decrease in the percentage of arboreal pollen (*Tilia*, *Quercus*). After that we see an increase in the *Betula* percentage, up to 13%, followed by an increase in *Corylus*, while the *Quercetum mixtum* also again increases.

The latter occurs together with a decrease in the percentage of herbs. The occurrence of this *Plantago* landnam, caused in Holland by members of the PF Beaker Culture (Waterbolk 1956; Van Zeist 1959) can easily be explained in the Wijnjeterp district. Several barrows of this culture occur in this district (Boeles 1951). Members of this culture must have entered Holland about 2 200 B. C. (Van der Waals & Glasbergen 1955).

Part of the Subboreal and the whole Subatlantic are missing.

BORING NO 213 (fig. 3 and 20)

In the profile of boring No 213, at a depth of 0,90 to ca 1,35 m under the surface, a loess deposit was found, on which a *Cyperaceae-Gramineae* peat was formed. Three samples were prepared and analysed. The deepest sample, from a depth of 1,60 m, and originating from a conglomerate of thin layers of fine sand and peat, contained no pollen grains, but the humus--containing loess and the peat above it were suitable for palynological investigation. The formation of peat here also began in the Older Dryas Period (Firbas zone Ib). The pollen spectra obtained from the two samples investigated can be compared with that from No 29B at a depth of 4,30—4,00 m. There is namely in both spectra an increase in the percentage of *Pinus* from 10—25%, a decrease in *Betula* from 80 to about 60%, and a decrease in *Salix* to less than 10%. In the spectra from boring 29B *Salix* is not found in a percentage greater than 10% above a depth of 4,30 m. The profile 29B from 4,40 to 4,20 m contained much more inorganic matter than samples above or below this depth. This indicates drifting of inorganic material into the pingo remnant, during the Older Dryas Period, while at the same time a loess deposit was formed outside the pingo.



Key to symbols for pollen-diagrams

BORING NO 167 (fig. 3 and 20)

At this point, the peat began at a depth of 0,83 m under the surface, and samples were taken from 0,83 to 0,39 m. Five samples were investigated and gave a diagram that was in the first place remarkable for a continuous *Fagus* curve. However the *Fagus* value remains very low (0,6%). It is certainly a Subboreal diagram, and it seems to be younger than the uppermost samples from boring 29B. Possibly the deepest samples from No 167 are of the same date as the uppermost samples from 29B (cf. the *Quercus* curve).

COMRARISON WITH SIMILAR INVESTIGATIONS

Several palynological investigations concerning peat formation in pingo remnants in Holland have been performed lately (Polak 1959; Casparie and Van Zeist 1960). There is also a palynological investigation of peat from the Siegerswoudster lake, (cf. Maarleveld and Van der Toorn 1955) which was performed by G. Jager (then biology student at Utrecht) for a thesis for Prof. Dr F. P. Jonker. Here also the beginning of peat formation in the Late Glacial Period but continuing into the Subatlantic [3].

[3] We wish to express our thanks to Prof. Dr. F. P. Jonker for permission to publish the above information.

The various diagrams are generally comparable, except for local factors, which at the Waskemeer, the Uddelermeer and Wijnjeterp are totally different. At Wijnjeterp there is an example of silting up in an eutrophic environment, whereas at Waskemeer and in the Uddelermeer it was in an oligotrophic one. The fact that an eutrophic environment remained during the whole of the peat formation at Wijnjeterp can be explained by the low--lying position of the pingo, in the middle of higher, nutrient boulder clay. Thanks to erosion effects caused by the Boorne and other water courses, a continuous stream of nutrient water was maintained. Fairly large amounts of secondary pollen were also found in the samples. The decrease in the percentage of *Alnus* in boring 29B at the point in the profile where the wood peat is replaced by *Cyperaceae* peat must be explained. There are two possibilities. Firstly a natural explanation, namely a rise in the ground water level, which would mean that the wood peat would be submerged, and the silting-up process would be set back a few steps. It would then have been possible for the *Alnetum* vegetation to be replaced by *Cyperaceae*. Something like this was found by Van Zeist (1958—59) and later by Janssen (1960). The natural grassland formed by this process may have been used for grazing by the PF Beaker people. But as Van Zeist has already postulated, it is possible that Man caused the decrease in *Alnus* to provide himself with grazing lands. The decrease in *Alnus* at Wijnjeterp is coupled with a decrease in the other tree pollen and an increase in the herb pollen, caused by the landnam. Moreover, we notice that part of the Subboreal and the whole Subatlantic peat is missing (cf. boring 29B and 167). The most acceptable reason for this is that this part was removed by peat exploitation. However, in the Archives of the Opsterlandse Veencompagnie (Visser 1957)[4] there is nothing about peat cutting to be found.

CONCLUSION

The formation of peat in an eutrophic environment in the pingo remnant at Wijnjeterp (gem. Opsterland, Friesland, boring 29B) began in the Older Dryas Period (Firbas period Ib) and, as far as we can see, continued

[4] Drs J. Visser (state archivist in Friesland) was kind enough to ask Mr. S. J. van der Molen if he knew anything about peat cutting in Wijnjeterp. Mr. van der Molen had no information about peat cutting at the site of the pingo remnant, only more to the south. Later Mr. Visser told us about a report from the abbott Sibrandus Leo (1570) saying that during the life of the abbott Syardus van Mariëngaarde (1194—1230) peat was cut in the Bakkeveen area. This indicates peat cutting long before the oldest archives of the Opsterlandse Veencompagnie (17th century). So the possibility remains that part of the Subboreal and the whole Subatlantic peat has been cut away.

until the Subboreal (period VIII). The profiles investigated gave us no information about the vegetation history at the end of the Subboreal and during the whole Subatlantic. The local vegetation in the pingo remnant (*Gramineae*, *Cyperaceae*, *Alnus*) rather confuses the issue, although several characteristic factors of peat formation since the last Ice Age are easily recognisable (zonation). In the topmost samples (Subboreal) the influence of Neolithic Man (PF Beaker culture) on the natural environment is to be seen (*Plantago* landnam).

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